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+Gz PROTECTION IN THE FUTURE - REVIEW OF SCIENTIFIC LITERATURE

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SUMMARY

To reduce the incidence of G-induced loss of consciousness and enable pilots to operate their aircraft at higher levels of performance, anti-G protection must be improved. A G-suit and the anti-G straining maneuver will likely remain essential components of any anti-G system, but several methods potentially increasing G-tolerance have been investigated that could supplement the protection afforded by these traditional techniques. Pharmacologic agents are of no benefit, while breathing carbon dioxide, shown to improve G tolerance, is impractical. Positive pressure breathing has so convincingly improved G-protection that it will become an operational procedure in the immediate future. The benefits of the G-suit have been augmented through greater coverage of the lower body and efforts are also aimed at more responsive G-valves. Altering body position to shorten the heart-to-head hydrostatic distance adds directly to the protection offered by the other procedures but can impair vision and must wait until the cockpit is redesigned.

INTRODUCTION

Today's fighter aircraft are capable of generating high and sustained levels of headward acceleration (+Gz; the symbol G will be used throughout to denote +Gz) and achieving these at high rates. A level of 9 G can be reached within one second. Current aircrew G protection systems allow peripheral vision in the unprepared pilot to fail at only 4-5 G. To increase G tolerance above that provided by the anti-G suit alone, anti-G straining maneuvers (AGSM) are performed by the pilot. These can increase his tolerance to 8 or 9 G but require mental concentration and are physically fatiguing. Clearly, additional methods of G protection are needed.

This chapter will review developments and recent experimental findings in the traditional forms of G protection and describe additional methods that may improve man's tolerance to G. Most of this work was accomplished in human centrifuges. Historical reviews (19,39,70) and recent discussions of G protective techniques (2,13,46) are available.

It is well established that problems of visual impairment and loss of consciousness in an upright sitting individual on exposure to high levels of headward acceleration are due to decreases in blood pressure at head level (70). In turn, this is due to the hydrostatic distance between the eyes and heart, and slight hypotension at heart level secondary to blood pooling in the venous system in dependent regions. Attempts to increase tolerance to sustained G may approach the problem by: (a) directly increasing arterial blood pressure at level of heart and eyes, (b) reducing the hydrostatic distance between heart and eyes, and (c) increasing blood pressure at heart level through reductions in venous pooling.

Techniques for directly increasing blood pressure are: (a) positive pressure breathing during G (PBG), and (b) hypertensive agents such as carbon dioxide in the inspired gas or pharmacologic means. Techniques for reducing the hydrostatic heart-eye distance are: (a) reclination of the seat back, and (b) use of the prone position. Techniques for reducing venous pooling are: (a) G-suits with greater body coverage, (b) improved G-valves, and (c) elevation of pelvis and legs. The protection provided by AGSM and the traditional G-suit is discussed elsewhere (13,70) and will not be covered here.

Before G tolerance can be assessed, the term tolerance and the conditions of the G environment must be defined. A useful and general definition of G tolerance would be the ability of man exposed to G to maintain consciousness and at least a minimum field of vision compatible with useful psychomotor performance. For physiological research and evaluation of G protective equipment, more specific criteria of G tolerance are required. One approach would be to present G in a continuously increasing mannner, e.g. a gradual onset rate (GOR) profile, and evaluate the constancy of some tolerance indicator. Possible indicators include: (a) bilateral visual field 25 degrees from centre; (b) maintenance of blood pressure at eye level; (c) performance on a given psychomotor task; and (d) elevated heart rate to a pre-determined level. A second approach would be to expose the individual to a specific G profile of set duration and measure the subject's responses after the exposure. Often evaluated are the amount of fatigue after the profile and the recovery of physiological and/or psychological variables. Thirdly, a profile of continuous G, or one of repeating cycles of low and high G, could be used. The subject's termination of this profile reflects his endurance. This may refer to his physical capacity or his ability to carry out a psychomotor task until performance deteriorates.

POSITIVE PRESSURE BREATHING

Positive pressure breathing is the application of pressure by a regulator to the breathing gas throughout the respiratory cycle. It is being used operationally for emergency hypoxia protection on exposure to altitude above approximately 12,000 meters. For positive pressure breathing to be effective, the oronasal mask-to-face seal must be adequate to prevent excessive gas leakage. Positive pressure breathing at levels up to approximately 30 mm Hg (1 mm Hg = 0.133 kPa) are acceptable, but induce fatigue at 1 G, because forceful muscle contraction is required for expiration. "Balanced" positive pressure breathing is the additional application of counter-pressure to the chest with a jerkin or vest. As the jerkin is pressurized by the same hose leading to the mask, this pressure will counter-balance any increased pressure in the lungs. This limits lung expansion and reduces fatigue by assisting expiration. With a jerkin, the level of positive pressure breathing may be as high as 60-70 mm Hg. (In this chapter, positive pressure breathing and PBG are to be assumed to be without chest counter-pressure. If balanced pressure breathing is being referred to, it will be so stated.)

The G protective benefits of PBG are similar to those of the AGSM. The increased intra-pulmonary pressure is transmitted to the left ventricle and intra-thoracic vessels, and results in an increase in systemic arterial pressure. The high intra-thoracic pressure may impair venous return and then decrease systemic blood pressure unless a G-suit maintains the pressure gradient between peripheral venous and central venous blood pressures. Although PBG had been used experimentally as early as 1944 (47), optimal methods of use and extent of its effects were unknown, and the procedure required substantial development.

Lowry et al. (52) studied PBG levels up to 25 mm Hg. Their subjects increased visual threshold by 0.5 - 0.9 G compared to the normal G-suit condition without PBG.

Chambers et al. (18) used a PBG schedule of 1.4 mm Hg/G up to 5 G with pure oxygen. Compared to regular breathing of air or oxygen, visual brightness discrimination requirements were significantly lower at 3 G with oxygen PBG, and there was a general ease of breathing and comfort.

Shubrooks (61) compared the M-1 AGSM and PBG at 40 mm Hg in conditions with G-suit inflation or abdominal and leg tensing. PBG did not change the G level at which peripheral light loss (PLL) was experienced during rapid onset rate (ROR, 1 G/sec) G profiles in the centrifuge. The subjects completed 45 sec at 8 G with the

M-1 or PBG, but they experienced less physical work with PBG. PBG also reduced the inspiratory-induced decreases in arterial pressure seen at eye level with M-1, and overall arterial pressure was more sustained with PBG.

A collaborative effort by USAFSAM and RAF-IAM (48) studied a series of 60 sec exposures at 3, 6, 8 G with the subjects using the M-1 or PBG (PBG 28-30 mm Hg when G > 2 G). There was no difference in G tolerance with PBG compared to the M-1 but PBG was less fatiguing, and at 3 and 6 G, the partial pressure of oxygen in arterial blood was greater with PBG.

Glaister and Lisher (34) flight tested PBG after observing in the centrifuge that PBG at 5 mm Hg/G (G > 2 G) augmented relaxed G tolerance by 0.8 G above that offered by the G-suit. The Type 517 breathing regulator was modified to cut in at 2.5 G with 12.5 mm Hg of mask pressure. Mask pressure increased by 5 mm Hg/G to a maximum of 35 mm Hg. With sorties attaining 6 G, the pilots found PBG acceptable and less tiring than the M-1. Speech was difficult, but with practice became intelligible. It was felt that PBG was not needed below 4 G.

Balanced positive pressure breathing was first studied as a G protective technique by Shaffstall and Burton (57) using 30 mm Hg in conditions: (i) with USAF G-suit, (ii) with RAF jerkin and USAF G-suit, (iii) with CF waistcoat-type jerkin and USAF G-suit, and (iv) with Swedish combination G-suit and chest counter-pressure garment. In relaxed, gradual onset rate (GOR) (1 G/10 sec) profiles, all PBG conditions increased G tolerance compared to the control tests with the G-suit only. For the simulated aerial combat maneuver (SACM) profile, in which G cycles repeatedly between 4.5 and 7 G, tolerance time using balanced PBG was 27% greater than in the G-suit and straining control tests. Tolerance time with unbalanced PBG was not different from control. It was felt that without a jerkin, pressure breathing with 30 mm Hg could promote fatigue due to constant expiratory muscle activity. Therefore, unbalanced PBG may be no more effective than the M-1 for G tolerance, but balanced PBG may be advantageous by reducing fatigue. Heart rate and oxyhemoglobin saturation were not different among the conditions.

Shaffstall and Burton (59) used profiles to 7 G to study tolerance time, heart rate, and performance in a tracking task in different PBG conditions: (i) control (no PBG), (ii) PBG 5 mm Hg/G starting at 1 G and maximum of 30 mm Hg at 7 G, (iii) PBG 5 mm Hg/G starting at 4 G with maximum of 15 mm Hg at 7 G, (iv) PBG with cut-in 17.5 mm Hg at 3.5 G then 5 mm Hg/G to maximum of 30 mm Hg at 7 G, and (v) PBG with 30 mm Hg continuous and starting before G. These schedules using unbalanced PBG did not improve G tolerance compared to the M-1, nor reduce the fatigue involved in maintaining vision and consciousness.

Using a SACM profile (5-9 G with 10 sec plateaus), Burns and Balldin (8) studied three experimental conditions: (i) control (G-suit and AGSM), (ii) CF jerkin-balanced PBG 50 mm Hg (cut-in at 1.2 G and increasing linearly to maximum of 50 mm Hg at 9 G), and (iii) balanced PBG 70 mm Hg (cut-in at 1.2 G and increasing to maximum of 70 mm Hg at 9 G). The profile end-points were light loss, fatigue or discomfort. With AGSM as necessary for maintenance of vision, tolerance time in

SACM increased by 115% with balanced PBG of 50 mm Hg compared to control. With balanced PBG 70 mm Hg, time increased by 88%. There was no difference in hemoglobin saturation at end of SACM or sustained 9 G, but saturation did not decrease as quickly with PBG 50 mm Hg. Heart rate was not altered. Although PBG 70 mm Hg should theoretically have provided the best protection with the greatest intra-thoracic pressure, uncomfortable nasopharynx distension and tightly fitted masks possibly shortened duration. PBG increased the inspired volumes and hemoglobin saturation was likely improved due to a better matching of regional ventilation and blood flow in the lungs.

Domaszuk (27) investigated constant PBG levels of 15, 30, 45 and 60 mm Hg in GOR profiles using a pressure helmet and full capstan-like suit (no additional G-suit). Compared to the relaxed control G tolerance, the four levels of PBG increased tolerance by 0.4, 1.8, 2.2, and 1.7 G respectively. PBG of 60 mm Hg was uncomfortable and 15 mm Hg was undetectable. In his second study, 45 mm Hg PBG was delivered in a G profile increasing at 0.2 G/sec then continuous at 5 G. PBG increased the duration of this test to 266% of control and reduced the heart rate.

Bagshaw (1) conducted flight trials with a PBG schedule of 5 mm Hg/G, starting at 4 G during increasing G, and terminating at 3 G during decreasing G. The press-to-test facility of the oxygen regulator was modified to deliver 100% oxygen during PBG, but deliver airmix before and after G. With instructions that straining could be added if needed, 71% of pilots felt that PBG increased tolerance to air combat maneuvers and was more effective than AGSM. Less fatigue was felt afterwards. The abrupt cut-in/cut-out of PBG at 4/3 G was considered to be less than ideal.

Prior et al. (56) found relaxed G tolerance, as indicated by visual criteria, was increased by 0.42 and 0.36 G by PBG and balanced PBG, respectively, compared to the G-suit only tolerance level of 5.55 G in ROR profiles. PBG was delivered at approximately 10 mm Hg/G starting at 4.0 G. This PBG system was unique in that the breathing regulator received a pneumatic signal from the anti-G valve outlet. On pressure from the anti-G valve, PBG would start. In PBG systems with independent G-sensitive devices, pressure breathing syncope could develop if there is not simultaneous G-suit inflation.

Harding and Cresswell (37) reported favourable comments from Hunter aircraft pilots testing PBG at 10.85 mm Hg/G (from 0 mm Hg at 2.3 G to 51 mm Hg at 7 G). Chest counter-pressure was a further advantage. Follow-up trials in the Hawk aircraft showed that balanced PBG (6 mm Hg/G with 13 mm Hg at 3 G to 45 mm Hg at 8 G) provided significantly more anti-G protection than unbalanced PBG or G-suit and straining alone.

In early 1987, USAF conducted flight trials in an F-16 fitted with prototype balanced PBG systems designed to assess their G protective capability and effects on aircraft operation. This technology had been developed from the work of Burns and Balldin at USAFSAM using 50 and 70 mm Hg balanced PBG. The maximum pressure level was 60 mm Hg at 9 G. The three pilots strongly endorsed PBG as an anti-G system, feeling that they were well-protected and probably could tolerate G loadings for longer durations and at greater than present limits. The prototype PBG systems, however, limited pilot mobility and comfort.

In flight trials with PBG of 13 mm Hg at 3 G to 45 mm Hg at 8 G, Cresswell et al. (24) found, according to subjective evaluations, balanced PBG to be significantly more effective at G protection than unbalanced PBG or straining alone.

Clere et al. (21) evaluated constant balanced PBG levels of 38, 53, and 68 mm Hg in relaxed GOR tests taken to 50% PLL. When PBG was applied at 2 G, the three pressures increased tolerance by 1.45, 1.5 and 2.5 G, respectively, compared to the G-suit only control test. Tolerance was increased by 1.83, 2.2, and 2.43 G, respectively, when PBG was applied once the subject had 50% PLL. PBG of 68 mm Hg always restored the full visual field. It was recommended that PBG should increase gradually from 4 G and that 68 mm Hg offered the best protection.

Balldin et al. (4) studied balanced PBG employing a pressure schedule of 10 mm Hg/G, starting at 4 G with a maximum of 50 mm Hg at 9 G. The seat back angle was 30 degrees. In relaxed GOR tests, the proportion of subjects enduring 9 G for 10 sec increased with PBG from 18 to 82%. In ROR tests using AGSM as needed to avoid visual grey-out, the proportion increased from 71 to 100%.

Presently, PBG is regarded as an important addition to the G protection system. By increasing intra-thoracic pressure, PBG reduces the fatigue associated with the AGSM when assistance is provided by external thoracic counter-pressure. Also, by providing increased pressures automatically with elevations in G, the pilot should be less concerned with adjusting the intensity of his straining effort. A more alert and less fatigued pilot should be able to maintain concentration on his flying tasks. Issues that remain to be resolved are the ideal PBG pressure/G schedule, the G level for PBG to cut in and out, and suitable headgear to maintain the appropriate pressures. As PBG will be introduced into service in 50 USAF F-16's in the early 1990's and probably incorporated in the new European Fighter Aircraft, facilities and programmes for training aircrew on the use of PBG will be needed.

HYPERTENSIVE AGENTS

Carbon dioxide may improve G tolerance because it is known to cause systemic vasoconstriction and cerebral vasodilation. Early reports by Ruff in 1938 and Matthes in 1940 suggested that G tolerance is increased by 0.5 G with inspirates of 4-6% carbon dioxide (cited in (29)).

Brachial arterial pressure of dogs and monkeys at 6 G was increased by approximately 20 mm Hg with 13% carbon dioxide compared with control (63). With 20% concentrations, the blood pressure was 45 mm Hg greater. It was necessary for carbon dioxide to be inhaled for at least 30-60 sec before, and continued through, the acceleration period. Because some of the blood pressure benefits were associated with increased pressure at 1 G, redistribution of blood volume was speculated as a further effect of carbon dioxide. The gas provided no G protective effect when given in concentrations of 5-10%. Any protection was less if carbon dioxide was breathed for more than 7-12 min.

Krutz (41) found that human volunteers breathing 5.2 and 7.9 % carbon dioxide increased G tolerance by 0.51 and 0.88 G, respectively, compared to air breathing control values. The ROR profiles were conducted in the relaxed mode.

Glaister (32) observed that relaxed G tolerance for GOR and ROR profiles increased by 0.8 and 0.9 G, respectively, when the inspirate contained 5% carbon dioxide and was given 2 min before the tests. With 7% carbon dioxide, tolerance was further increased by 0.4 and 0.7 G, respectively. Carbon dioxide however caused breathing discomfort and extreme headache.

Howard (39) reviewed the effect on G tolerance of pharmacologic agents that theoretically could increase vasomotor tone and/or blood pressure. Generally, their effect is negligible. A list of tested drugs includes: analeptics, adrenaline, adrenaline and ephidrine, atropine, amphetamine sulphate, anti-malarial agents, oestradiol and testosterone, paredrine, and sodium diphenylhydrantonin. Adrenocorticoids and posterior pituitary extracts also failed to improve G tolerance.

RECLINED SEATS

As one factor determining blood pressure at head level is the vertical height between the head and heart, reclining the seat back away from the vertical will result in greater blood pressure at head level.

Crossley and Glaister (26) studied back angles of 70, 45, 30, 25, 20 and 15 degrees from the horizontal. At 70 degrees from the horizontal, GOR and ROR tolerance levels, determined by PLL, were 4.5 and 3.3 G, respectively. The tolerance levels were 7.3 and 5.7 G, respectively, at 15 degrees. The grey-out threshold was found to be proportional to the inverse of the vertical eye-heart distance (distance calculated as the sine of seat back angle from the horizontal) and the threshold was significantly improved when the back angle was 45 degrees or less from horizontal. Wearing a G-suit further increased relaxed G tolerance even though the thighs were positioned above, and the heels positioned level with the hips. This action may have been due to an increase in peripheral vascular resistance. It was concluded that the near supine position with a G-suit can provide relaxed thresholds between 6-8 G while permitting adequate forward visibility.

Burns (7) found no difference in G tolerance between the control seat back angle of 13 degrees from vertical and 30 degrees. At 45 degrees from vertical, tolerance increased by 0.5 G. At 75 degrees, the tolerance of 8 G represented a 100% increase over the control level. The thighs and legs were below hip level. Heart rate and the intra-thoracic pressure required to maintain the visual field were decreased with greater seat back angles. Tolerance was again highly correlated with the inverse of the eye-aorta distance.

A reclined seat produces a greater +Gx component on the body with greater respiratory difficulty during G, therefore Glaister and Lisher (33) used PBG to help raise the anterior chest wall. With a PBG schedule of 5 mm Hg/G to 35 mm Hg maximum, the relaxed grey-out threshold of 3.49 G in the conventional seat was increased to 4.89 G with the seat angled 65 degrees from vertical. As found earlier, the addition of the G-suit increased G threshold and each increment of pressure in the G-suit schedule added protection. The normal expiratory reserve volume at 1 G was maintained at 4 G with PBG, suggesting that a similar work of breathing was restored.

Gillingham and McNaughton (30) used visual field limit tracking during relaxed GOR profiles to 7 G. Complete visual loss occurred at or near 5 G when the seat back angle was 13 degrees from vertical. At 45 degrees, there was complete visual loss at or near 6 G. When the seat back was at 65 degrees, substantial vision remained at 7 G.

Glaister and Lisher (35) utilized a psychomotor performance test with a high motor demand to assess the benefits of reclination to 60 degrees from the vertical compared to 17 degrees. With a pressurized G-suit and PBG at 5 mm Hg/G to a maximum of 40 mm Hg, performance at 6 and 8 G improved in the reclined seat, equivalent to 1-2 G of additional protection. Heart rate was similar at 8 G reclined compared to 5 G upright.

Following-up with a psychomotor test with greater mental effort, Lisher and Glaister (51) studied seat back angles of 17, 52, and 67 degrees from vertical. Compared to the 17 and 52 degree positions, 67 degrees raised the acceleration level at which a performance decrement occurred by 1.4 G.

Glaister (31) reviewed published data on the effect of seat back angle on G tolerance in relaxed and unprotected, protected with G-suit only, and G-suit with straining or PBG conditions. G tolerance in each condition was described by a different mathematical relationship but all were proportional to the inverse of cosine of the angle of seat back and the G vector. Independent of the condition, the regressions predicted that seat back angles of 58, 69 and 74 degrees would deliver 1.0, 2.0 and 3.0 G increases in grey-out tolerance, respectively, compared to the upright seat. Tolerance would be further increased by 1.21 G with the G-suit and by 3.15 G with full protection from the G-suit and straining or PBG.

Burton and Shaffstall (15) measured increases in endurance time of 38, 98, and 218% in the SACM profile when the seat back angles were 30, 55 and 65 degrees from vertical, respectively, compared to the control value at the 13 degree position. Heart rate 120 seconds into the profile was significantly less at the 55 and 65 degree angles.

Cohen (23) reported that seat reclination to 75 degrees increased relaxed G tolerance by 3.12 G. If used with a G-suit and/or straining maneuver, reclination offered the same increase in protection.

Burns and Whinnery (9) radiographically measured the hydrostatic distance between the eye and aortic valve at postures of 30 and 65 degrees from vertical seat back angle, each with a headrest geometry of 12, 25 and 45 degrees up from the reclination line. Relaxed G tolerance significantly correlated with the inverse of this hydrostatic distance. While headrest geometry had no effect on G tolerance at a seat back angle of 30 degrees, lowering the head from 45 to 12 degrees at the 65 degree back angle, increased mean tolerance by 1.7 G. Nelson (54) has calculated that the aortic valve is the most appropriate reference position for the hydrostatic theory of visual blackout.

G tolerance is significantly improved with seat reclination beyond 45 degrees from the vertical but the position causes practical problems (5,66) of vision difficulties and breathing impairment, and would require a re-design of the cockpit. PBG could alleviate the respiratory problems.

PRONE POSITION

Similar to reclination, the prone position augments tolerance to positive acceleration by decreasing the heart-eye hydrostatic distance. The increased protection was apparent in experiments performed in Germany and the U.S. in the late 1930's and early 1940's. Generally, vision was unaffected at 9 G sustained for 10 sec.

Clark et al. (20) found that in the prone position, humans could tolerate up to 12 Gx (labelled Gx because the inertial vector is perpendicular to the body's long axis). There were no visual symptoms when the head and trunk were level. Complete blackout occurred in some subjects at 10-12 G if the head was lifted 4-6 inches above the trunk.

The prone position however places excessive pressure on certain body points. Chin pressure and interference with speech were partly overcome by supporting the helmet with cable, pulley and counter-weight. Special couches alleviated the back and torso pressure. Breathing is more laboured in this position, although is not as difficult as in the supine position, and there can be pain in the extremities due to blood pooling in dependent regions, fluid drip from the nose, petechial rashes, displacement of the eyelids in the dependent direction, lacrimation, and salivation. Views in the upward and rearward directions remain seriously impaired.

The prone position is preferred over the supine because there is less displacement of the heart and less over-distension of the lungs at high vertical G.

GREATER COVERAGE ANTI G-SUITS

In a significant investigation of G protection, Wood and Lambert (68) found that for every unit of increase in G, systolic blood pressure at heart level decreased 3 mm Hg while diastolic pressure remained unchanged. At eye level, blood pressure decreases per G increase were 32 mm Hg systolic and 19 mm Hg diastolic. With a G-suit, systolic and diastolic blood pressure at heart level increased 5 mm Hg per G increase, while at the level of the eye, the normal decreases were reduced to 20 and 14 mm Hg, respectively. Later, it was found that the effectiveness of the G-suit to increase G tolerance improved with increases in lower body coverage to the maximum area provided by the standard five-bladder suit, and by greater inflation pressure (69). Water immersion also increased G tolerance (36). These observations are consistent with the principle that the G-suit should apply uniform pressure over as much of the lower body as possible.

The pressurized G-suit improves G tolerance through three modes of action: (i) increasing peripheral vascular resistance (50) by developing high tissue pressure in the lower limbs; (ii) preventing the normal descent of the diaphragm during G by supporting the abdominal wall; and (iii) limiting the blood volume collecting in the capacitance system of the abdomen and legs through the high counter-pressure. The first two actions contribute to limiting the decrease in arterial blood pressure at the beginning of exposure to G. By helping to maintain the central blood volume, the third action supports blood pressure during extended exposure to G.

The standard 5 bladder G-suit has been widely accepted because its design and inflation method were highly practical and because it offered G protection equivalent to the limits of the aircraft when combined with properly performed AGSM. However, efforts have been made to augment the protection provided by the lower body garment. Early ventures resulted in G-suit designs incorporating circumferential bladders (62) and principles from the lower half of a full pressure altitude suit (22,49,62). Such altered designs out-performed 5 bladder suits by approximately 1 G in relaxed, G tolerance tests. This was achieved by increases in arterial pressure through greater increases in peripheral arterial resistance and maintenance of a greater blood volume in the thoracic viscera compared to the standard suit (62). Some of these full coverage suits were uncomfortably restrictive around the lower rib cage and abdomen, bulky, and required longer pressurization times. They may however need less pressure for equivalent protection (49).

Other versions of the early G-suit provided a gradient of counter-pressure from the ankles up to the trunk, or were designed to completely occlude the arterial inflow to the limbs (70). The former was technically complex and offered no greater protection than the single pressure, 5 bladder suit, while the latter, although significantly increasing G tolerance, caused ischemic pain in the arms and legs.

The capstan G-suit, which applies pressure to the skin through the tightening effect of inflated pneumatic levers, offered no extra protection for relaxed G tolerance compared to the standard 5 bladder suit (14). When the inflation pressure in the suits was increased, their performance remained comparable. In a subsequent investigation in which the counter-pressures exerted by the standard G-suit and a capstan suit were similar, SACM tolerance time with the capstan suit was increased by 133% (58). The difference in the relative effect of the capstan suit compared to the regular bladder G-suit in these two studies may have been due to a lower level of counter-pressure exerted by the capstans (45) in the earlier study.

Krutz and Burton (42) compared a modified CSU-4/P pressure suit designed to provide uniform lower body and abdomen pressurization through a full bladder, with the CSU-15/P G-suit using tests of incremental ROR G profiles until PLL. The full coverage G-suit increased G tolerance by 0.6 G. According to heart rate criteria, the full suit inflated to 5 psi (1 psi = 6.89 kPa) at 6 G offered protection equivalent to 65 degrees of seat back reclination.

The Tactical Life Support System developed for USAF in 1987, in addition to providing PBG, incorporates more coverage by the five-bladder G-suit (6,53), the suit volume being increased by approximately 45%. Limited tests at USAFSAM demonstrated approximately a 0.5 G improvement in tolerance.

Krutz and Burton (43) studied the standard five-bladder G-suit, a reticulated foam uniform pressure suit, and a pneumatic uniform pressure suit with bladders arranged to form a cylinder around the limbs. In GOR, very high G onset rate (6/sec), and SACM G profiles, the pneumatic uniform pressure suit provided more protection, increased endurance and was subjectively preferred compared to the other two suits. It was reasoned that the benefits were due to increased venous return and maintenance of peripheral circulation without pooling. Impedance plethysmographic measurements suggest that, while the standard G-suit limits the amount of blood pooling occurring in the lower body during G, the pneumatic uniform pressure suit further decreases the blood volume in the calves and thighs and displaces it upward to increase abdominal blood volume (44).

Balldin et al. (3) observed that a full coverage lower body suit increased GOR tolerance by 0.4 G compared to the standard suit. Time to visual grey-out in SACM was longer with the full suit and some subjects could sustain 9 G for a short period without straining. With the full coverage suit, the peak heart rate was lower and less petechiae were observed, but hemoglobin saturation, ratings of perceived exertion and comfort were unchanged.

Prior (55) observed increases in the relaxed G threshold for PLL from 5.2 G with the standard G-suit to 6.5 G with a G-suit that covered all body parts below the umbilicus, except the ankles and toes. When PBG was added according to a schedule of 9 mm Hg/G, the threshold increased to 8.3 G. It was suggested that the gains might be largely due to coverage of the gluteal region. The full coverage G-suit was comfortable, but restricted leg mobility.

IMPROVED ANTI-G VALVES

The protection provided by the G-suit depends greatly on the G-valve pressurizing it. The G-valve must deliver the correct pressure at the correct time. Henry et al. (38) altered the time at which G-suit inflation began relative to the attainment of 2.5 G during 15 sec centrifuge runs up to 5 G. G protection, according to PLL, was at its maximum when the start of inflation occurred within a range extending from approximately 10 sec before, to the moment coincident with passing through 2.5 G. G-suit inflation beginning 5 sec after reaching 2.5 G decreased protection by approximately 13%. This was lowered to 50% with a delay of 10 sec. The rate of G onset was approximately 3.4 G/sec above 2.5 G. Reaching 3 G was recommended as the latest point for starting G-suit inflation.

Until the 1970's, the performance of the G-valve was adequate. But in tactical fighters capable of sustained, high G maneuvers, and attaining high G at previously unattainable rates, the G-valve was a limiting factor to a pilot's performance. Since head-level arterial blood pressure begins to decrease immediately upon application of G, and one benefit of the G-suit is to provide hypertension at heart level which is achieved through increases in systemic vascular resistance, it is logical to expect that the G-valve should provide pressure coincident with the G profile. Surprisingly, the evidence is not conclusive on this issue.

Burton et al. (14) found that inflating the standard G-suit to 1 psi at the start of centrifugation, increased G tolerance by 0.4 in ROR profiles. This pre-inflation procedure pressurizes the G-suit approximately 3 sec ahead of the normal schedule.

In 1979, a mechanical G-valve (ALAR Products Inc.) that provided an increased flow rate, in addition to pre-acceleration inflation, was evaluated (16). Reducing the G-suit inflation times by approximately 75% in bench tests, subsequent centrifuge and flight tests rated it to have a high degree of acceptance, allow pilots to use less effort at high levels of G, and improve G tolerance by approximately 1 G over the standard valve.

An electronic G-valve has been developed in which the pressure to the G-suit is controlled by the voltage difference between the output of an accelerometer and a G-suit pressure transducer (25). The G-valve output pressure is able to track the G profile and results in a delay of only 0.5 sec in G-suit pressurization. In comparisons using very rapid G onset rates and 15 sec sustained G centrifuge profiles, the electronic valve improved G tolerance compared to the standard mechanical G-valve. The increases were 0.5 and 1.3 G with subjects in the relaxed and straining modes, respectively. G-suit pressure was developed according to $P=1.5(G-1)$psi, $(1.5<G<8.3)$, with a maximum of 11 psi.

When G is greater than 2 G and the rate of onset is greater than 2 G/sec, a solenoid in an electro-mechanical valve opens for a set period, i.e. 1.5 sec, to maximally inflate the G-suit (64). The necessary G-suit pressure is then determined by the valve's standard, mechanical characteristics. This valve improved G tolerance by 1 G compared to the standard valve in relaxed subjects exposed to 15 sec constant G at 3 G/sec onset rate.

Cammarota (17) found that the ALAR high-flow G-valve, a rapid response servo valve, and a servo valve programmed to anticipate the onset of G by 500 ms, all offered similar protection for G tolerance in ROR profiles, and duration tolerance in SACM tests, but these were greater than the protection offered by the standard ALAR G-valve.

Burton (11) evaluated the allowable delay in G-suit inflation for light loss criteria to be significantly affected. Compared to the maximum inflation rate condition which would allow G-suit pressure to reach 5 psi 0.2 sec before attaining 7 G, a mean delay of 3.3 sec had no effect on relaxed G tolerance with 6 G/sec onset rate to the final G plateau. With a 4.2 sec delay, light loss occurred earlier. In AGSM conditions with 6 G/sec to 7 G, a mean 2.8 sec delay decreased protection, but 2.0 sec did not. It was concluded that inflation of the G-suit could be delayed by at least 1 sec after reaching maximum G without compromising its protection.

Frazier et al. (28) proposed that with microprocessor controlled anti-G valves, the G-suit pressure/G schedule need not necessarily be linear. At 3 G and under, where G-LOC is unlikely, pressure could be less than the Military Specification. Pressure could be greater than the specification if the G level was above 5 G where loss of vision and G-LOC were possible.

Jaron et al. (40) developed a valve that pulsates the G-suit. Pressure in the various compartments of the G-suit is cycled between positive and negative excursions around the mean value equal to the standard G-suit pressure. In GOR and ROR G profiles, the best protection was obtained when all bladders were inflated simultaneously to a positive level during each cardiac systole. Thorough comparisons with standard protection have yet to be reported.

PELVIS AND LEGS ELEVATION

In addition to investigating various seat back angles, Voge (65) measured the effect of changing the position of the legs on PLL threshold. At a seat back angle of 45 degrees from the vertical, and the thighs at 59 degrees from vertical, there was no difference in G tolerance, 6.3 compared to 6.5 G, when the lower legs where at 115 degrees from vertical or hanging vertically respectively. The addition of a G-suit increased the G tolerance in each position, in agreement with other findings (26). The greatest G tolerance, 11.1 G, was obtained with the seat back at 75 degrees and the thighs resting on the chest ("fetal" position), however this posture produced complaints of tiredness, pressure on the chest and legs, and general discomfort.

Approximately a 0.4 G increase in relaxed grey-out threshold can be achieved by elevation of the feet (60). This is believed to be a result of decreased vaso-dilatation and veno-distension in the lower legs. Others suggest that elevation of the feet has no anti-G benefits (12).

CONCLUDING REMARKS

Several methods of supplementing the G protection now provided by the 5 bladder G-suit and AGSM have been described. Carbon dioxide must be breathed before the G exposure, and the headache and breathlessness it provokes would be unacceptable features of flying, even if only in an anticipatory mode. No pharmacologic agent has demonstrated G protective value and there may always be the risk of undesirable side effects.

The usefulness of the remaining methods depend on whether the posture of the pilot can be altered. Changes in posture deal effectively with the single greatest reason for G intolerance, the heart-to-head hydrostatic distance. Indeed 10 G could be easily sustained. As the G protective benefits of G-suits, reclination, and increases in intra-thoracic pressure can be combined according to an additive model, 11.8 G is predicted to be tolerated with a 55 degree reclined seat and a PBG/AGSM combination of 100 mm Hg (10). But the price of reclination may be too great. Changes in posture require a redesign of the cockpit that is already too late for next generation tactical fighters. Vision out of the canopy and movement of head and limbs are impaired with the more horizontal posture. The respiratory system would become the G-limiting physiological system. PBG could assist breathing in different postures. Tolerance time at 10 G of forward acceleration was increased by 67% with 19 mm Hg of PBG (67). Dyspnea however still remained the main reason for terminating the runs, even though the PBG level used was that preferred by the subjects.

Whether the seat back is upright or reclined, greater coverage G-suits and their faster inflation hold promise for improving G-tolerance. When combined with PBG, such a modernized anti-G system will confer great improvements in endurance to pilots at submaximal levels of G, and will make G-induced loss of consciousness less frequent in high intensity, short duration G. Importantly, such a system could be used in present generation aircraft. The challenge will be to make a greater coverage G-suit practical and to produce a reliable G-valve that will deliver the larger gas volumes when needed.

Whatever the form of the G protective system, the AGSM will be a major part of it, even with PBG, and particularly if anti-G equipment fails. Therefore, aircrew must not take for granted, their ability to perform a proper AGSM .

REFERENCES

1. Bagshaw, M. Royal Air Force, Institute of Aviation Medicine. A flight trial of positive pressure breathing during acceleration using RAF Hawk aircraft at a tactical weapons unit, 1984, IAM Report No. 637.

2. Balldin, UI. Physiological methods for protection against high sustained Gz acceleration. Physiologist, 26 (Suppl), 1983, S14-S17.

3. Balldin. UI, GO Dahlback, LE Larsson. Full coverage anti-g suit. Aviat. Space Environ. Med. 59, 1988, 480.

4. Balldin. UI, GO Dahlback, LE Larsson. Forsvarets Forskningsanstalt. Full coverage anti-g-suit and balanced pressure breathing. FOA Rapport, C 50065-5.1, February 1989.

5. Barnes, AG. The design of a high 'g' cockpit. In: Fighter Aircraft Design, AGARD-CP-241, 1978, pgs 27-1 - 27-12.

6. Buick, F, JAG Porlier. Design specifications for protection against high +Gz. Tactical Life Support System, Contract F33615-83C.0615, Project 596 - Phase I Deliverables, Task IIB-1 Preliminary Report, November 1983.

7. Burns, JW. Re-evaluation of a tilt-back seat as a means of increasing acceleration tolerance. Aviat. Space Environ. Med. 46, 1975, 55-63.

8. Burns, JW, UI Balldin. +Gz protection with assisted positive pressure breathing (PPB). In: Preprints of Annual Scientific Meeting of Aerospace Medical Association, 1983, pgs 36-37. (Full report: Aviat. Space Environ. Med. 59, 1988, 225-233)

9. Burns, JW, JE Whinnery. Significance of headrest geometry in +Gz protective seats. Aviat. Space Environ. Med. 55, 1984, 122-127.

10. Burton, RR. A conceptual model for predicting pilot group G tolerance for tactical fighter aircraft. Aviat. Space Environ. Med. 57, 1986, 733-744.

11. Burton, RR. Anti-G suit inflation rate requirements. Aviat. Space Environ. Med. 59, 1988, 601-605.

12. Burton, RR, PF Iampietro, SD Leverett. Physiologic effects of seat back angles < 45 degrees (from the vertical) relative to G. Aviat. Space Environ. Med. 46, 1975, 887-897.

13. Burton, RR, SD Leverett, ED Michaelson. Man at high sustained +Gz acceleration: a review. Aviat. Space Environ. Med. 45, 1974, 1115-1136.

14. Burton, RR, MJ Parkhurst, SD Leverett. +Gz protection afforded by standard and preaccleration inflations of the bladder and capstan type G-suits. Aerospace Med. 44, 1973, 488-494.

15. Burton, RR, RM Shaffstall. Human tolerance to aerial combat maneuvers. Aviat. Space Environ. Med. 51, 1980, 641-648.

16. Burton, RR, RM Shaffstall, JL Jaeggars. Development, test, and evaluation of an advanced anti-G valve for the F-15. Aviat. Space Environ. Med. 51, 1980, 504-509.

17. Cammarota, J. The effect of AGS inflation speed on G-tolerance. Aviat. Space Environ. Med. 58, 1987, 505.

18. Chambers, RM, R Kerr, WS Augerson, DA Morway. U.S. Naval Air Development Center, Aviation Medical Acceleration Laboratory. Effects of positive pressure breathing on performance during acceleration, 1962, NADC-MA-6205.

19. Christy, RL. Effects of radial, angular, and transverse acceleration. In: Aerospace Medicine, 2 ed, Ed: HW Randel, Baltimore, Williams and Wilkins Company, 1971, pgs 167-197.

20. Clark, WG, JP Henry, PA Greely, DR Drury. Committee on Aviation Medicine, Office of Scientific Research and Development. Studies on flying in the prone position, 1945, Report No. 466. Cited in: EH Wood. Development of anti-G suits and their limitations. Aviat. Space Environ. Med. 58, 1987, 699-706.

21. Clere, JM, D Lejeune, D Tran-cong-chi, H Marotte, JL Poirier. Effect of different schedules of assisted positive pressure breathing on G-level tolerance. In: Proceedings of SAFE Symposium, Las Vegas, NV, 1988.

22. Cochran, LB. US Naval School of Aviation Medicine. A study of the half pressure anti-blackout suit. 1954, Research Report No. NM-001-059.15.03.

23. Cohen, MM. Combining techniques to enhance protection against high sustained accelerative forces. Aviat. Space Environ. Med. 54, 1983, 338-342.

24. Cresswell, GJ, D McPhate, RM Harding, EW Farrer. Positive pressure breathing with and without chest counterpressure - an assessment in air combat manoeuvring flight. Aviat. Space Environ. Med. 59, 1988, 480.

25. Crosbie, RJ. Naval Air Development Center. A servo controlled rapid response anti-G valve. 1983, Report NADC-83087-60.

26. Crossley, RJ, DH Glaister. Effect of posture on tolerance to positive (+Gz) acceleration. In: Adaptation and Acclimatisation in Aerospace Medicine, AGARD-CP-82, 1971, pgs 6-1 - 6-6.

27. Domaszuk, J. The application of positive pressure breathing for improving +Gz acceleration tolerance. Aviat. Space Environ. Med. 54, 1983, 334-337.

28. Frazier, JW, T Gordon, LJ Meeker. Anti-G suit pressure - how much is just right? In: Preprints of NAECON Meeting, 23-27 May, 1988.

29. Gauer, OH, GD Zuidema. The Physiology of Positive Acceleration. In: Gravitational Stress in Aerospace Medicine. Eds: OH Gauer, GD Zuidema. Boston, Little Brown and Co., 1961, pgs 115-133.

30. Gillingham, KK, GB McNaughton. Visual field contraction during G stress at 13, 45, and 65 degree seatback angles. Aviat. Space Environ. Med. 48, 1977, 91-96.

31. Glaister, DH. RAF Institute of Aviation Medicine. The influence of seat back angle on acceleration tolerance, 1978, FPRC/1365.

32. Glaister, DH. Physiological aspects of high-G protection, sustained acceleration and impact forces. In: Seventh Advanced Operational Aviation Medicine Course, AGARD-R-697, 1984, pgs 8-1 - 8-8.

33. Glaister, DH, BJ Lisher. Centrifuge assessment of a reclining seat. In: The Pathophysiology of high sustained +Gz acceleration, Limitation to Air Combat Manoeuvering and the Use of Centrifuges in Performance Training, AGARD-CP-189, 1976, pgs A4-1 - A4-8.

34. Glaister, DH, BJ Lisher. Pressure breathing as a means of enhancing tolerance to sustained positive accelerations. In: Proceedings of a Symposium on Biomedical and Biophysical Aspects of Oxygen Systems, 17th Meeting of Air Standardization Coordinating Committee, Working Party 61, Farnborough, Hants, November 8-12, 1976, pgs 138-144.

35. Glaister, DH, BJ Lisher. RAF Institute of Aviation Medicine. The effect of a reclined sitting position on psychomotor performance during exposure to high, sustained +Gz acceleration, 1977, FPRC/1362.

36. Gray, RF, MG Webb. High G protection. Aerospace Med. 32, 1961, 425-430.

37. Harding, RM, GJ Cresswell. Royal Air Force flight trials of positive pressure breathing. In: Proceedings of a Symposium on High G and High G Protection, Aeromedical and Operational Aspects. Royal Aeronautical Society, London, 1987, pgs 62-71.

38. Henry, JP, WG Clark, WH Tracy, DR Drury. Committee on Aviation Medicine of National Research Council. Determination of the effect of time of inflation on the G protection gained form the Clark G-4 suit. 1944, Report No. 398.

39. Howard, P. The physiology of positive acceleration. In: A Textbook of Aviation Physiology, Ed: JA Gillies, Oxford, Pergamon Press, 1965, pgs 551-687.

40. Jaron, D, TW Moore, BRS Reddy, L Hrebien, F Kepics. Increased acceleration protection with an improved pulsating anti-G suit. Aviat. Space Environ. Med. 59, 1988, 480.

41. Krutz, RW. Effects of elevated CO2 breathing mixtures on +Gz tolerance. In: Review of Air Force-sponsored Basic Research in Environmental and Acceleration Physiology, Brooks AFB, 8-10 October 1974.

42. Krutz, RW, RR Burton. The effect of uniform lower body pressurization on +Gz tolerance and protection. In: Preprints of Annual Scientific of Aerospace Medical Association, 1974, pgs 62-63.

43. Krutz, RW, RR Burton. A comparison of uniform pressure anti-G suits. In: Proceedings of 25th SAFE Symposium, Las Vegas, NV, 1987, pgs 50-53.

44. Krutz, RW, RR Burton, EM Forster. Physiologic correlates of protection afforded by anti-G suits. Aviat. Space Environ. Med., 1989 (in press).

45. Krutz, RW, MI Darrah. Current research and development of anti-G suits. SAFE J. 14, 1984, 26-27.

46. Krutz, RW, SD Leverett, RR Burton, JW Burns. +Gz protective methods for use in advance fighter-attack aircraft. In: Current Status in Aerospace Medicine, AGARD-CP-154, 1975, pgs C6-1 - C6-5.

47. Lambert, EH. Subcommittee on Acceleration of the National Research Council. Self-protective maneuvers combined with anti-blackout suits. February, 1944. Cited in: EH Wood, EH Lambert. Some factors which influence the protection afforded by pneumatic anti-g suits. J. Aviat. Med. 23, 1952, 218-228.

48. Leverett, SD, RR Burton, RJ Crossley, ED Michaelson, SJ Shubrooks. USAF School of Aerospace Medicine. Physiologic responses to high sustained +Gz

acceleration, 1973, SAM-TR-73-21.

49. Lewis, DH. An analysis of some current methods of G protection. J. Aviat. Med. 26,1955, 479-485.

50. Lindberg, EF, WF Sutterer, HW Marshall, RN Headley, EH Wood. Measurement of cardiac output during headward acceleration using the dye dilution technique. Aerospace Med. 30, 1960, 817-834.

51. Lisher, BJ, DH Glaister. Royal Air Force, Institute of Aviation Medicine. The effect of acceleration and seat back angle on performance of a reaction time task, 1978, FPRC/1364.

52. Lowry, RH, F Girling, GF Smith. Defence Research Board, DND Canada. The effect of breathing under pressure when humans are subjected to increasing forces of acceleration. February, 1953.

53. Michas, RD, JC Steffler, F Buick, KN Ackles. Tactical Life Support System (TLSS) Aircrew Integrated Garment. In: Proceedings of Symposium, Integration of the Aircrewman, his Equipment and the Crewstation. 26th Meeting of Air Standardization Coordinating Committee, Working Party 61, Farnborough, Hants, November 1985, pgs 66-74.

54. Nelson, JG. Hydrostatic theory and G protection using tilting aircrew seats. Aviat. Space Environ. Med. 58, 1987, 169-173.

55. Prior, ARJ. Royal Air Force, Institute of Aviation Medicine. Centrifuge assessment of the +Gz acceleration protection afforded by full coverage anti-G trousers, 1988, Aircrew Equipment Report No. 572.

56. Prior, ARJ, JA Bass, J Tervit. Royal Air Force, Institute of Aviation Medicine. Positive pressure breathing and chest counterpressure for enhanced +Gz tolerance using NGL anti-g module and regulator 1654E000, 1986, Aircrew Equipment Report No. 537.

57. Shaffstall, RM, RR Burton. Evaluation of assisted positive-pressure breathing on +Gz tolerance. In: Preprints of Annual Scientific Meeting of Aerospace Medical Association, 1977, pgs 80-81. (Full report: Aviat. Space Environ. Med. 50, 1979, 820-824)

58. Shaffstall, RM, RR Burton. Evaluation of a uniform pressure anti-g suit concept. In: Preprints of Annual Scientific Meeting of Aerospace Medical Association, 1980, 96-97.

59. Shaffstall, RM, RR Burton. Evaluation of unassisted positive-pressure breathing on +Gz tolerance. In: Preprints of Annual Scientific Meeting of Aerospace Medical Association, 1982, 18-19.

60. Sharp, GR. Protection against long duration acceleration. In: Aviation Medicine - Physiology and Human Factors. Eds G Dhenim, GR Sharp, J Ernsting. London, Tri-med Books Ltd, 1978, pgs 242-249.

61. Shubrooks, SJ. Positive pressure breathing as a protective technique during +Gz acceleration. J. Appl. Physiol. 35, 1973, 294-298.

62. Sieker, HO, EE Martin, OH Gauer, JP Henry. Wright Air Development Center. A compartive study of two experimental pneumatic anti-g suits and the standard USAF G-4A anti-g suit. 1953, WADC-TR-52-317.

63. Van Middlesworth, L, RF Kline. Protection against acceleratory forces by carbon dioxide inhalation. Amer. J. Physiol. 152, 1948, 22-26.

64. Van Patten, RE, TJ Jennings, W. Albery, JW Frazier. Development of an electro-pneumatic anti-G valve for high performance aircraft. SAFE J. 15, 1985, 10-13.

65. Voge, VM. Psycho-physiological assessment of acceleration-induced changes in various seat configurations. Aviat. Space Environ. Med. 48, 1977, 527-538.

66. von Beckh, HJ. Positioning of aircrews - ultima ratio of G protection? Aerospace Med. 43, 1972, 743-754.

67. Watson, JF, NS Cherniak. Effect of positive pressure breathing on the respiratory mechanics and tolerance to forward acceleration. Aerospace Med. 33, 1962, 583-588.

68. Wood, EH, EH Lambert. The effect of anti-blackout suits on blood pressure changes produced on the human centrifuge. Fed. Proc. 5, 1946, 115-116.

69. Wood, EH, EH Lambert. Some factors which influence the protection afforded by pneumatic anti-g suits. J. Aviat. Med. 23, 1952, 218-228.

70. Wood, EH, EH Lambert, EJ Baldes, CF Code. Effects of acceleration in relation to aviation. Fed. Proc. 5, 1946, 327-344.

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SUMMARY

To reduce the incidence of G-induced loss of consciousness and enable pilots to operate their aircraft at higher levels of performance, anti-G protection must be improved. A G-suit and the anti-G straining maneuver will likely remain essential components of any anti-G system, but several methods potentially increasing G-tolerance have been investigated that could supplement the protection afforded by these traditional techniques. Pharmacologic agents are of no benefit, while breathing carbon dioxide, shown to improve G tolerance, is impractical. Positive pressure breathing has so convincingly improved G-protection that it will become an operational procedure in the immediate future. The benefits of the G-suit have been augmented through greater coverage of the lower body and efforts are also aimed at more responsive G-valves. Altering body position to shorten the heart-to-head hydrostatic distance adds directly to the protection offered by the other procedures but can impair vision and must wait until the cockpit is redesigned.

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anti-G protection
G-induced loss of consciousness
G-suit
positive pressure breathing
G-valves

Acceleration tolerance
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